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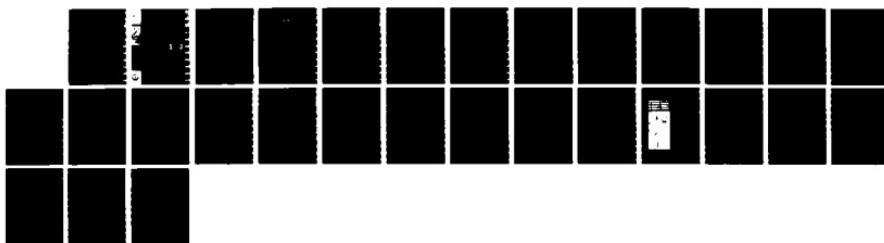
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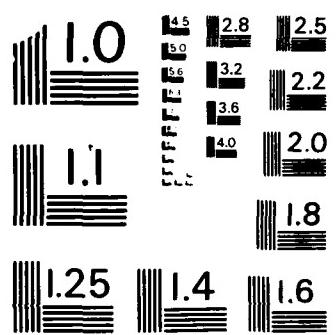
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CALIBRATION AND STABILITY CHARACTERISTICS OF THE BAYLOR STAFF WAVE GAGE

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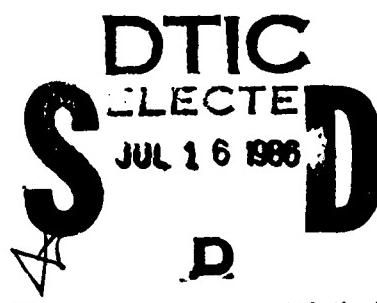
William E. Grogg, Jr.

Coastal Engineering Research Center

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631, Vicksburg, Mississippi 39180-0631

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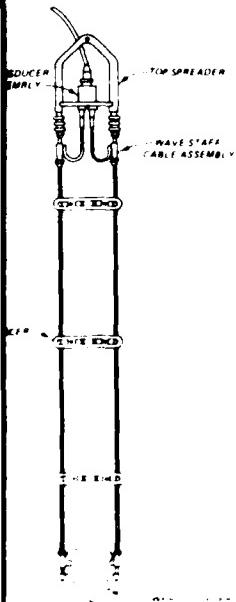
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The Coastal Engineering Research Center has used Baylor staff wave gages to gather prototype wave data at their Field Research Facility since 1978. This paper describes the theory of operation, calibration techniques, salinity effects, and suggested precautions to improve the reproducibility of long-term wave height measurements.		

PREFACE

This report was prepared at the US Army Engineer Waterways Experiment Station (WES) Coastal Engineering Research Center's (CERC's) Field Research Facility (FRF) in Duck, N. C. The report was prepared by Mr. William E. Grogg, Jr., Electronics Technician, under direct supervision of Mr. Curtis Mason, Chief, FRF Group, Research Division and under general supervision of Dr. James R. Houston, former Chief, Research Division, and present Chief, CERC.

Messrs. Eugene W. Bichner, Civil Engineering Technician; Stephen C. Wheeler, Computer Specialist; Robert T. Battalio and David A. Bradley, Summer Aides, assisted with data collection. This report was edited by Ms. Shirley A. J. Hanshaw, Publications and Graphic Arts Division, WES.

Director of WES during publication of this report was COL Allen F. Grum, USA. Technical Director was Dr. Robert W. Whalin.

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CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI
(metric) units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
feet	0.3048	metres
inches	2.54	centimetres

CALIBRATION AND STABILITY CHARACTERISTICS OF THE
BAYLOR STAFF WAVE GAGE

PART I: INTRODUCTION

1. Since 1977, the Coastal Engineering Research Center (CERC) has used Baylor wave staffs to collect data at CERC's Field Research Facility (FRF) in Duck, North Carolina (Birkemeier, et al. 1985).* Based on CERC's subsequent experience with these instruments, this paper has been developed to assist users of the gages in determining their operating characteristics, maintenance requirements, and accuracy.

* Birkemeier, et al., 1985. "A User's Guide to the Coastal Engineering Research Center's (CERC's) Field Research Facility, Instruction Report CERC-85-1, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

PART II: GAGE DESCRIPTION

General

2. Baylor staff wave gages are parallel inductive cable gages manufactured by the Baylor Company in Houston, Texas. The basic system consists of a twin wire rope staff, power supply, transducer element, and amplifier.

3. The wire rope staff consists of two parallel 0.5-in.* wire cables held under tension at a distance of 9 in. apart (Figure 1). At the FRF, the upper spreader is supported under a concrete and steel research pier, and the lower spreader is connected to an anchoring system in the ocean bottom (Figure 2). The power supply is regulated at 24 V direct current (VDC) and supplies input power to the transducer. The transducer element utilizes the wire rope staff as an inductor in a circuit excited at a fixed frequency.

4. The change in inductance produced by a variation in the water level on the gage causes a linear change of output voltage. The output of the transducer element is directly proportional to the exposed (unsubmerged) portion of wire rope and is approximately 0.05 V/ft of unsubmerged staff. Therefore, a fully submerged staff would produce 0 VDC; 30 ft of staff above the water would produce 1.5 VDC. An amplifier fabricated by CERC is utilized to amplify and convert the signal to 0 VDC for minimum water level (bottom of gage) and +5 VDC for maximum water level (top of gage). A fully submerged staff would produce an output of 5 VDC, and 30 ft of staff above the water would produce an output of 0 VDC.

Calibration Procedures

5. Since each transducer's output characteristics are different, the transducer must be calibrated in the laboratory prior to installation into any Baylor gage system. For gages installed on the FRF pier, the calibration setup consists of a 31-ft staff wave gage held horizontally between two supports marked at 1-ft intervals. The transducer is mounted on a plate in a configuration identical to that used in the field. A shorting bar is then

* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

installed between the cables at the marked points, and the voltage of each point is recorded. The output of a typical calibration is shown in Table 1.

PART III: GAGE SENSITIVITY ANALYSIS

6. Seven transducers were used with four different wave staffs to determine the sensitivity of the gage output to the following potential sources of error:

- a. Input voltage versus output. The effects on transducer output voltage versus changes in input voltage due to power supply drift or losses due to cable length.
- b. Transducer drift. Drift due to changes from component aging and stability.
- c. Power supply. Drift variation in input voltage due to power supply drift.
- d. Transmission line losses. Losses in input voltage at the transducer due to cable length from regulated power supply to transducer.
- e. Variance in wave staff cables. Errors due to differences between wire rope staffs.
- f. Input cable orientation. Changes in output voltage due to cable mounting orientation at the transducer between wire rope staff and transducer.
- g. Amplifier drift. Changes in output over time from the CERC amplifier.

PART IV: TEST RESULTS

Input Voltage Versus Output

7. Prior to 1981, all transducers were calibrated using an input voltage of 24 VDC. This did not take into consideration the voltage loss due to the cable which connects the power supply to the transducer. This loss is constant and should not change. Table 2 shows the voltage loss for each gage installed at the FRF. To determine the gage's performance under variable power supply voltages, the output from each of the seven transducers was measured as the input voltage was varied from 22 to 24.5 VDC at 0.2-VDC increments. For each voltage, the cable was shorted every 5 ft between 0 and 30 ft using a 9-in. shorting bar. Table 3 and Figure 3 show the output voltages obtained for one of the transducers over the typical range of power supply input voltages. The other transducers showed similar results. Table 3 and a graph of the cable length versus output voltages for input voltages between 22.059 and 23.054 VDC (Figure 3) show that a greater range in output voltages occurs at the 30-ft end than at the 0-ft end of the cable. These data also indicate a change of 8 percent in V/ft which is the calibration used at the FRF. Therefore, for greatest reproducibility, the transducers should be operated using exactly the same input voltage as that supplied to the transducer during calibration.

Transducer Drift

8. To test the stability of the transducer output over a long time period, the seven transducers were calibrated on 8 and 9 December 1980 and checked again approximately 3 months later. Figure 4 shows the results for one of these transducers. A small change in output (less than 0.5 percent voltage) compared to other sources of error was observed. Note that the transducer's linearity did not change.

Power Supply Drift

9. To determine the stability of the power supplies (nominally 24 VDC), their output was measured over a period of time. As shown in Table 4, the

24 VDC-regulated power supply outputs were very stable, and variation would have produced less than 0.5 percent difference in gage output.

Transmission Line Losses

10. The effect of line loss from power supply to transducer was evaluated by measuring the power supply voltage at each of the transducer inputs (Table 2). These data show a decrease of 0.3 VDC for every 500 ft of cable due to electrical losses within the cable.

Variance in Wave Staff Cables

11. Four different sets (three sets of 30-ft and one set of 28-ft cable) of 0.5-in. diam wave staff cables were tested on two transducers. Results of this test for one of the transducers (Table 5) indicate that all cables gave similar values, though one deviated about 0.7 percent from the others. The other transducer showed similar results.

Input Cable Orientation

12. The orientation of the two leads connecting the wave staff to the transducer was varied using the configurations shown in Figure 5. The wave staff was shorted at 0 ft, and the output from the transducer was measured for each one of the configurations. Figure 5 shows a maximum of 1 percent change in the gage output at 0 ft. This is due to the change in lead separation. To eliminate this potential source of error, the leads should be installed as shown in Figure 5g. A 9-in. spacer should also be used on the leads to assure proper separation.

Amplifier Drift

13. The wave gage amplifiers installed at the FRF on 11 September 1979 were continuously checked for drift between March 1980 and April 1984.

14. Initially, a voltage corresponding to the 0-ft level on the gage was input to the amplifier, and the amplifier output was set at 0 V affecting only the mean water level. Then at twice-a-week intervals the same input

voltages were applied, the corresponding amplifier outputs measured and recorded, and the amplifier output reset to zero. Figures 6a and 6b show the time variation of these outputs for the 4-year period. Note that after November 1980 the drift was very close to zero. At that time it was determined that some of the integrated circuits of the amplifiers were drifting. By replacing the integrated circuits and calibrating at regular intervals, the drift was greatly reduced.

15. The output drift of the amplifier was also determined by measuring changes in the maximum output voltage, nominally 5 VDC. Figures 7a and 7b show that over the 4-year period there was less than a 0.5 percent change in maximum output values due to amplifier drift.

PART V: SALINITY EFFECTS ON GAGE PERFORMANCE

16. An inductance wave staff such as the Baylor gage is dependent on salinity variations in the surrounding water. As part of a study to determine wave characteristics in a low-salinity environment, a special Baylor gage calibration facility was constructed, and salinity effects were investigated.

17. A 15-ft-deep, 12-in.-diam fiberglass well was filled with salt water, and a 10-ft wave staff was inserted into the well in 1-ft increments. Calibration runs were made at about 5 ppt increments from 5 to 35.5 ppt. Power from a single source was used for all calibrations.

18. Early in these salinity tests it was found that little change in gage output occurred within the lower 3 ft of cable. It was determined that the lower spreader connecting the bottom ends of the cables was affecting this part of the gage. Additional experience gained with gages installed on the FRF pier confirms that data from the bottom 3 ft of gage are unusable.

19. Subsequent tests of gage output versus water elevation were conducted over a wide range of salinities. Figure 8 shows the previously mentioned nonlinearity in response to the lower 3 ft of gage (i.e. between 7 and 10 ft) and the variation in gage linearity as a function of salinity. The output voltage as a function of distance along the gage usually decreased with a decrease in salinity. For example, a 10-ft wave height in water having 35.5 ppt salinity would appear as a 9.6-ft wave in salinity of 25.5 (i.e. 4 percent error). Within the range of salinities measured, as much as a 20 percent error (Table 6) in wave height could result from this effect.

20. Note also the differences between the shorting bar calibration recommended by the manufacturer and the actual values for various salinities. Apparently, using gage output factors based on the shorting bar calibration may induce errors of at least 4 percent under normal seawater salinity conditions. Additional tests were made using three 28-ft and two 31-ft cables in a 30-ft well filled with seawater at a salinity of 32.5 ppt. Nine transducers were used to determine the operational differences between calibration in seawater versus the shorting bar technique. Results of these tests showed a difference of only 0.5 percent in wave height measurement, but the gage 0 value shifted as much as 6 percent from the shorting technique to actual calibration in seawater. This error is critical only when using the gages for

mean water level. Additional tests are being conducted to determine the accuracies of these gages for measuring mean water level.

PART VI: CONCLUSIONS

21. From these tests, the following conclusions can be made regarding the operation and calibration of a Baylor wave gage:

- a. When installing a transducer, it is important to calibrate the transducer using the exact input voltage that will be applied to the transducer during operation. The same wave staff configuration should also be used, including spacing, length of lead from wave staff to transducer, and shorting bar used during calibration.
- b. The transducers should be calibrated every 6 months.
- c. Unless special precautions are taken, amplifier drift will reduce gage accuracy. By calibrating amplifiers each month and replacing integrated circuits (IC's) that drift, errors due to drift have been reduced to less than 0.5 percent at the FRF.
- d. The power supply should be checked for drift every 6 months (depending on the type of power supply used).
- e. Over the normal range of seawater salinities (30 to 35 ppt), gage output may vary as much as 2.0 percent. The gages can be used in variable salinity environments, provided they are calibrated for the expected salinity range.
- f. When all possible precautions have been incorporated to ensure gage reproducibility, repetitive long-term wave height measurements can be obtained within a reproducibility of 4.8 percent (Table 7).

Table 1
Baylor Sensing Cable Calibration Table, Feet of
Sea Water Versus Transducer Output Voltage

Sensing Cable ft	Output V	Gage Calibration Factor mv/ft
0	0.682	
1	0.708	26
2	0.741	33
3	0.775	34
4	0.807	32
5	0.840	33
6	0.873	33
7	0.906	33
8	0.940	34
9	0.973	33
10	1.006	33
11	1.039	33
12	1.073	34
13	1.105	32
14	1.138	33
15	1.171	33
16	1.204	33
17	1.239	35
18	1.271	32
19	1.303	32
20	1.338	35
21	1.370	32
22	1.404	34
23	1.437	33
24	1.469	32
25	1.502	33
26	1.536	34
27	1.569	33
28	1.602	33
29	1.634	33
30	1.667	33
31	1.700	33

Table 2
Input Voltage Loss

Gage No.	Power Supply Output V	Approximate Line Distance ft	Gage Input V	Loss V	Loss mv/ft
615	23.8	520	23.2	0.5	0.96
635	23.7	595	23.3	0.4	0.67
645	23.8	668	23.4	0.4	0.60
655	23.8	780	23.3	0.5	0.65
665	23.7	930	23.1	0.6	0.65
675	23.7	1,265	22.9	0.8	0.63
625	23.6	1,710	22.7	0.9	0.53

Table 3
Input Volts Versus Output

Input V	Cable Length, ft							V/ft*
	0	5	10	15	20	25	30	
22.059	0.756	0.949	1.146	1.344	1.543	1.741	1.945	0.0396
22.256	0.763	0.958	1.158	1.356	1.557	1.751	1.958	0.0398
22.456	0.770	0.966	1.169	1.369	1.572	1.774	1.976	0.0402
22.655	0.777	0.975	1.179	1.381	1.586	1.790	1.994	0.0406
22.854	0.784	0.984	1.190	1.394	1.601	1.806	2.012	0.0409
23.054	0.791	0.993	1.200	1.407	1.615	1.823	2.030	0.0413
23.256	0.798	1.002	1.211	1.420	1.630	1.839	2.041	0.0414
23.453	0.805	1.011	1.222	1.432	1.644	1.855	2.061	0.0419
23.660	0.812	1.020	1.232	1.445	1.658	1.872	2.087	0.0425
23.852	0.819	1.028	1.243	1.457	1.673	1.888	2.104	0.0428
24.051	0.826	1.037	1.254	1.470	1.688	1.905	2.122	0.0432
Range								
	0.070	0.088	0.108	0.126	0.145	0.164	0.158	0.0036

* Voltage per foot is derived by taking the maximum voltage (30-ft cable length) minus the minimum voltage (0-ft cable length) and dividing by length of cable (ft).

Table 4
Variation in Output from 24V Power Supplies

Date	Gage No.					
	615	635	645	655	665	675
21 Jan 81	23.803	23.726	23.810	23.804	23.711	23.711
4 Feb 81	23.809	23.735	23.806	23.792	23.756	23.714
13 Feb 81	23.809	23.735	23.806	23.792	23.756	23.714
25 Feb 81	23.799	23.718	23.782	23.759	23.684	23.696
12 Mar 81	23.770	23.730	23.771	23.824	23.782	23.712
16 Apr 81	23.794	23.745	23.793	23.814	23.712	23.718
	Range					
	0.039	0.027	0.039	0.065	0.098	0.022

Table 5
Voltage Variance in Wave Staff Cables

Distance Along Gage Cable ft	Output of Cable No. 1 V	Output of Cable No. 2 V	Output of Cable No. 3 V	Output of Cable No. 4 V
0	0.750	0.756	0.749	0.866
1	0.786	0.790	0.784	0.900
2	0.827	0.830	0.820	0.938
3	0.870	0.869	0.858	0.978
4	0.911	0.907	0.896	1.017
5	0.951	0.946	0.936	1.055
6	0.992	0.985	0.974	1.095
7	1.033	1.024	1.014	1.134
8	1.074	1.062	1.054	1.172
9	1.116	1.102	1.092	1.212
10	1.156	1.142	1.131	1.250
11	1.198	1.180	1.171	1.291
12	1.239	1.219	1.212	1.329
13	1.280	1.258	1.248	1.368
14	1.322	1.298	1.287	1.408
15	1.363	1.336	1.326	1.446
16	1.404	1.375	1.366	1.484
17	1.447	1.414	1.406	1.524
18	1.487	1.453	1.447	1.563
19	1.528	1.492	1.485	1.602
20	1.570	1.531	1.524	1.641
21	1.612	1.571	1.563	1.680
22	1.652	1.608	1.603	1.719
23	1.694	1.647	1.642	1.759
24	1.735	1.684	1.681	1.798
25	1.776		1.720	1.836
26	1.816		1.760	1.874
27	1.858		1.798	1.914
28	1.898		1.837	1.951
29	1.940		1.874	1.988
30	1.977		1.911	

Table 6
Salinity Versus Calibration Factor

<u>Salinity ppt</u>	<u>Gage Linearity (V/ft)</u>	<u>Difference from Shorting Bar %</u>
5.0	0.0283	25.5
10.0	0.0297	21.8
14.2	0.0332	12.6
19.0	0.0348	8.4
25.5	0.0357	6.1
30.0	0.0365	3.9
35.5	0.0373	1.8
<u>Shorting Bar</u>		
	0.0380	0.0

Table 7
Worst Case Error Analysis

<u>Source</u>	<u>Pre-1981 %</u>	<u>Post-1981 %</u>
Input voltage versus output voltage	8.0	0.5
Transducer drift	0.5	0.5
Power supply drift	0.5	0.5
Wave staff cables	0.7	0.7
Amplifier drift	3.5	0.5
Salinity	<u>2.1</u>	<u>2.1</u>
Total	15.3	4.8

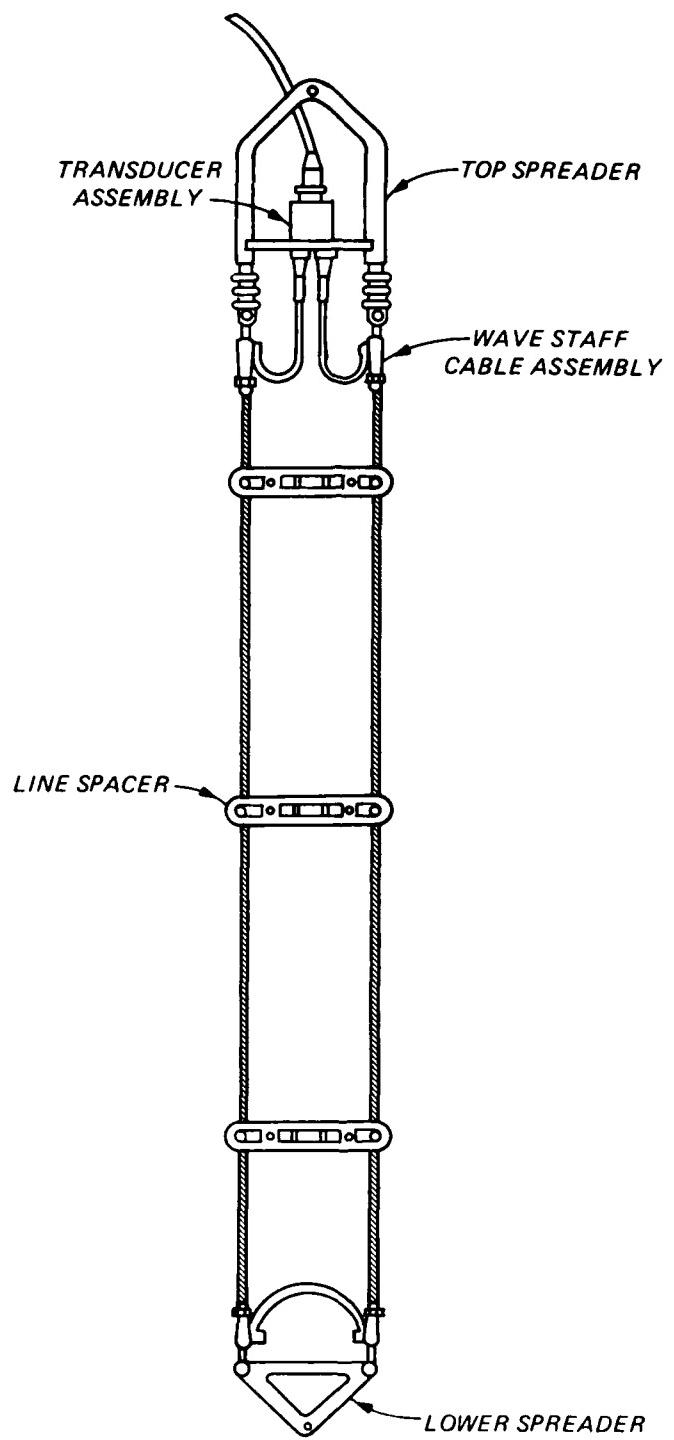


Figure 1. Free space staff wave gage assembly

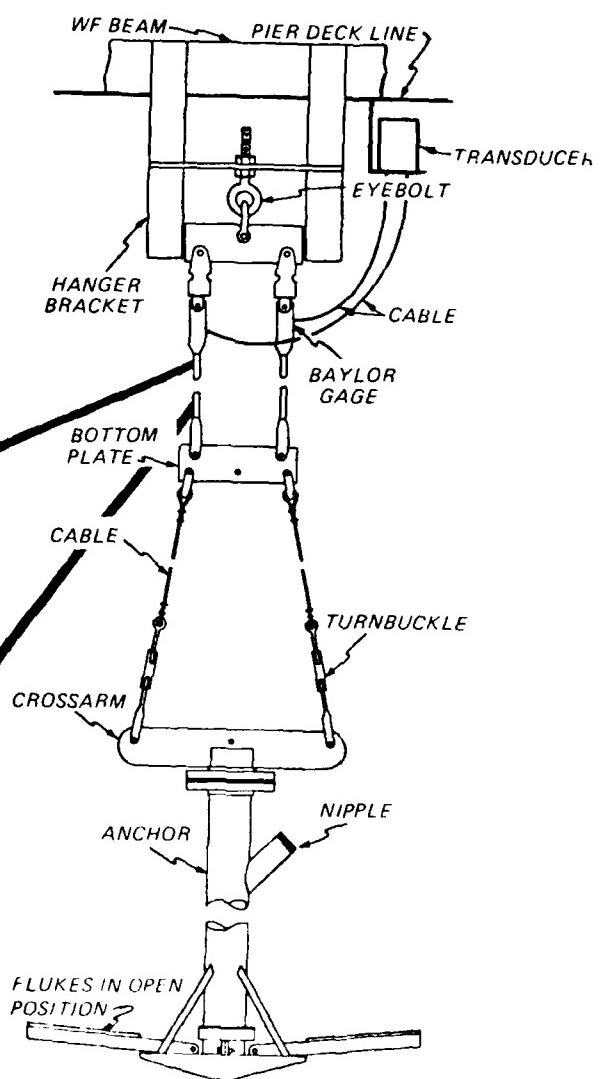


Figure 2. Baylor staff wave gage and support system

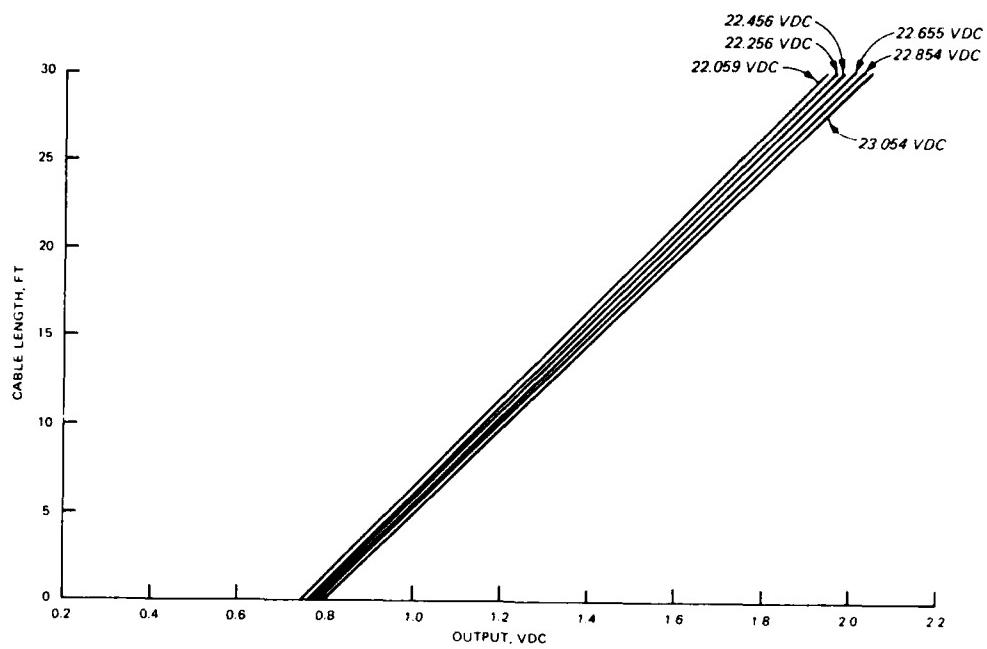


Figure 3. Input voltage versus output voltage, Baylor transducer

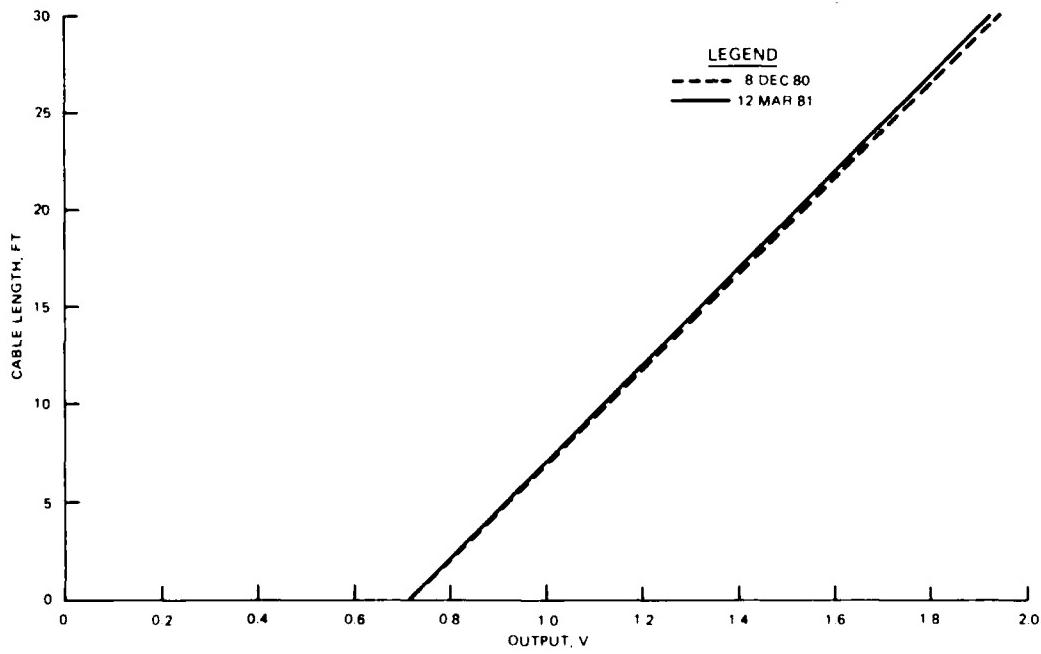


Figure 4. Transducer stability results

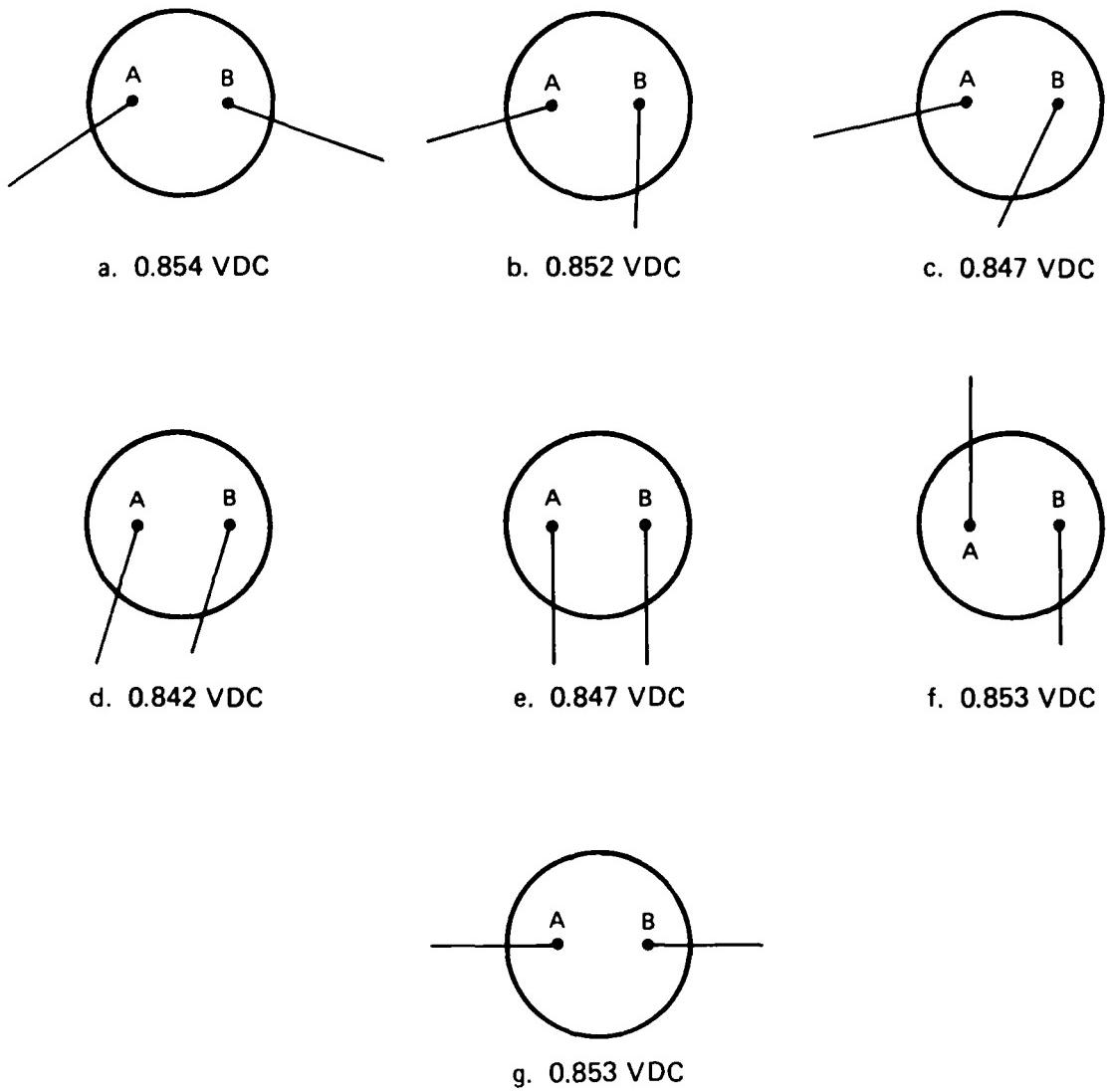
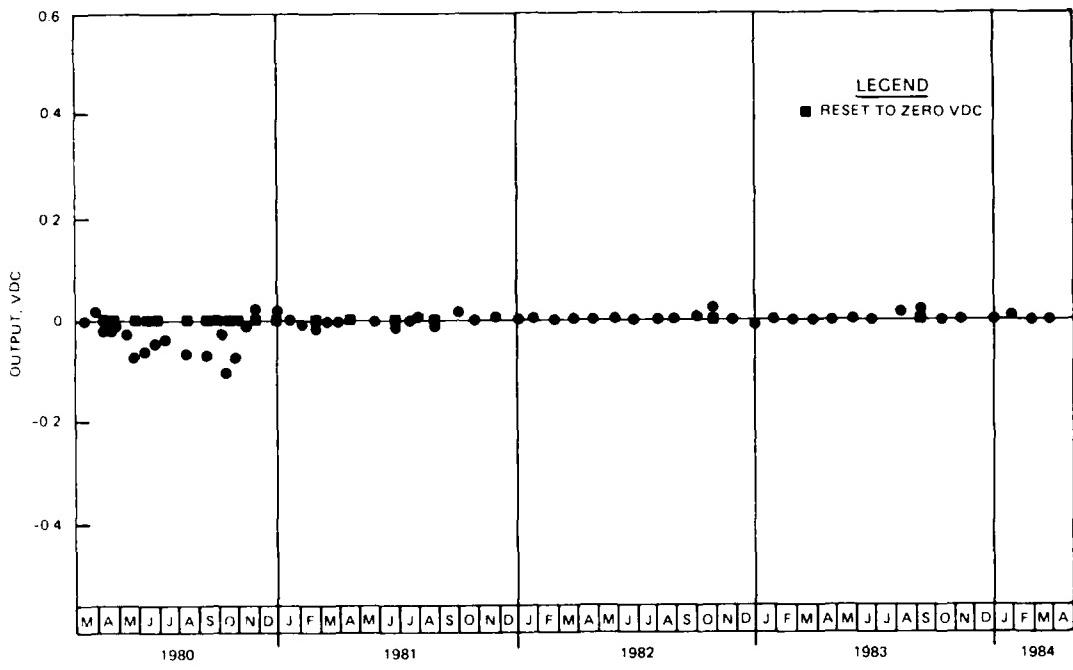
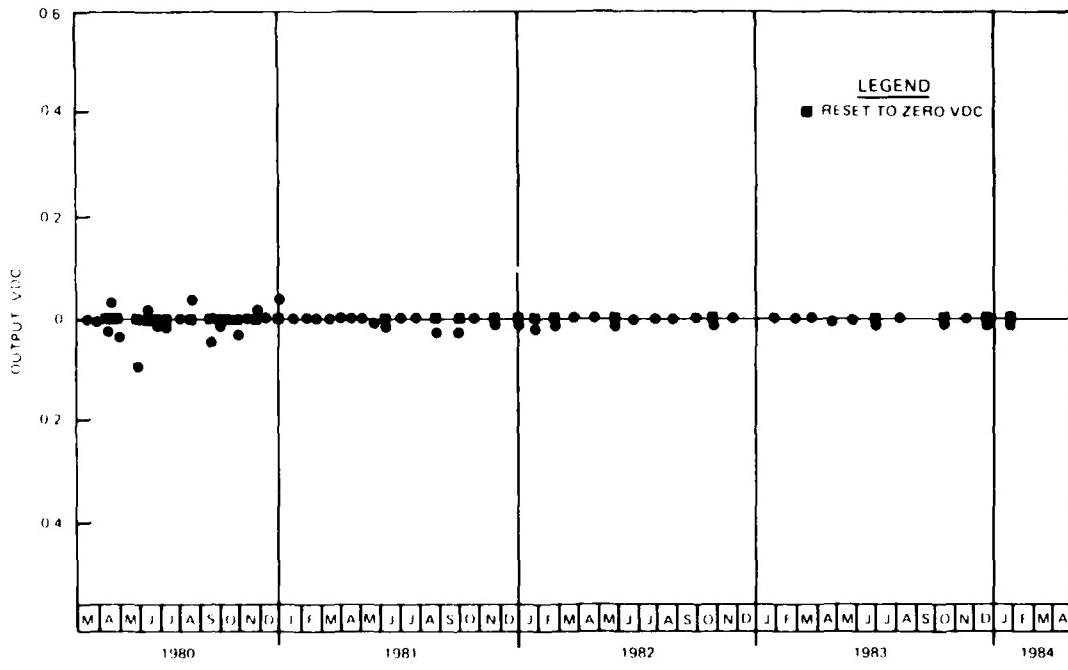


Figure 5. Configuration for transducer lead orientation

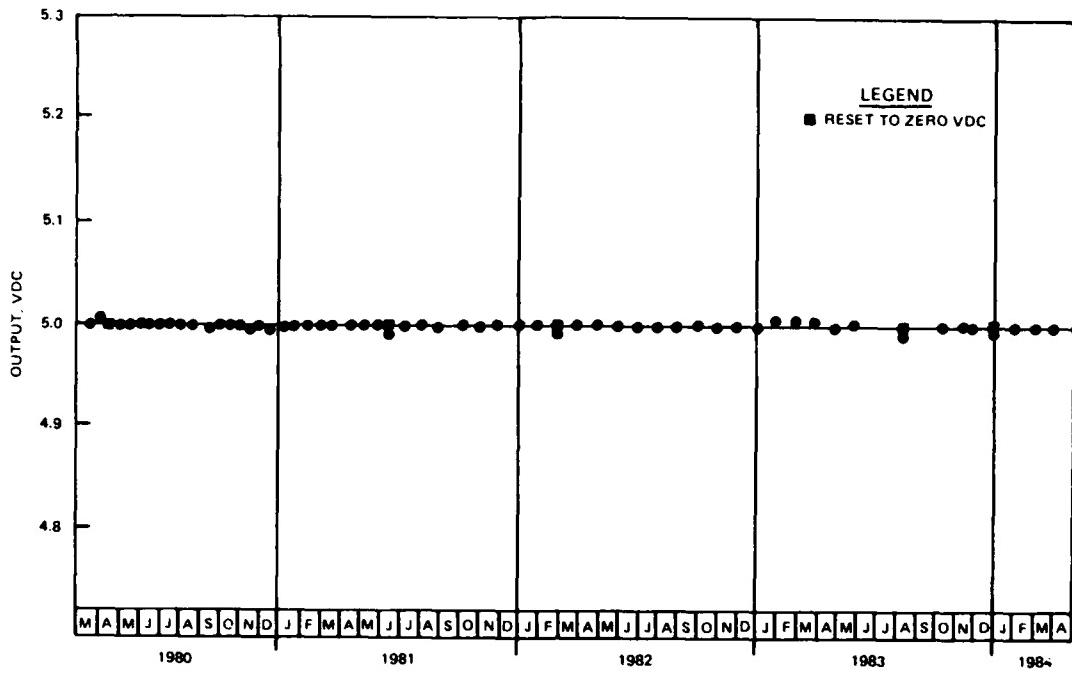


a. Gage 615

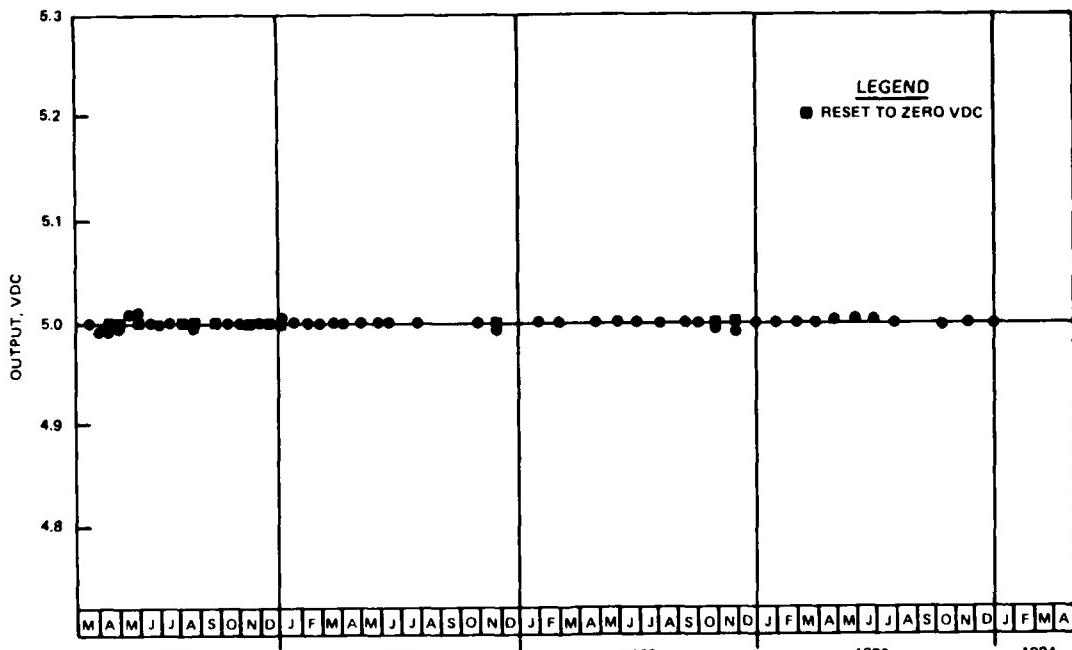


b. Gage 625

Figure 6. Amplifier zero stability



a. Gage 615



b. Gage 625

Figure 7. Full-scale drift

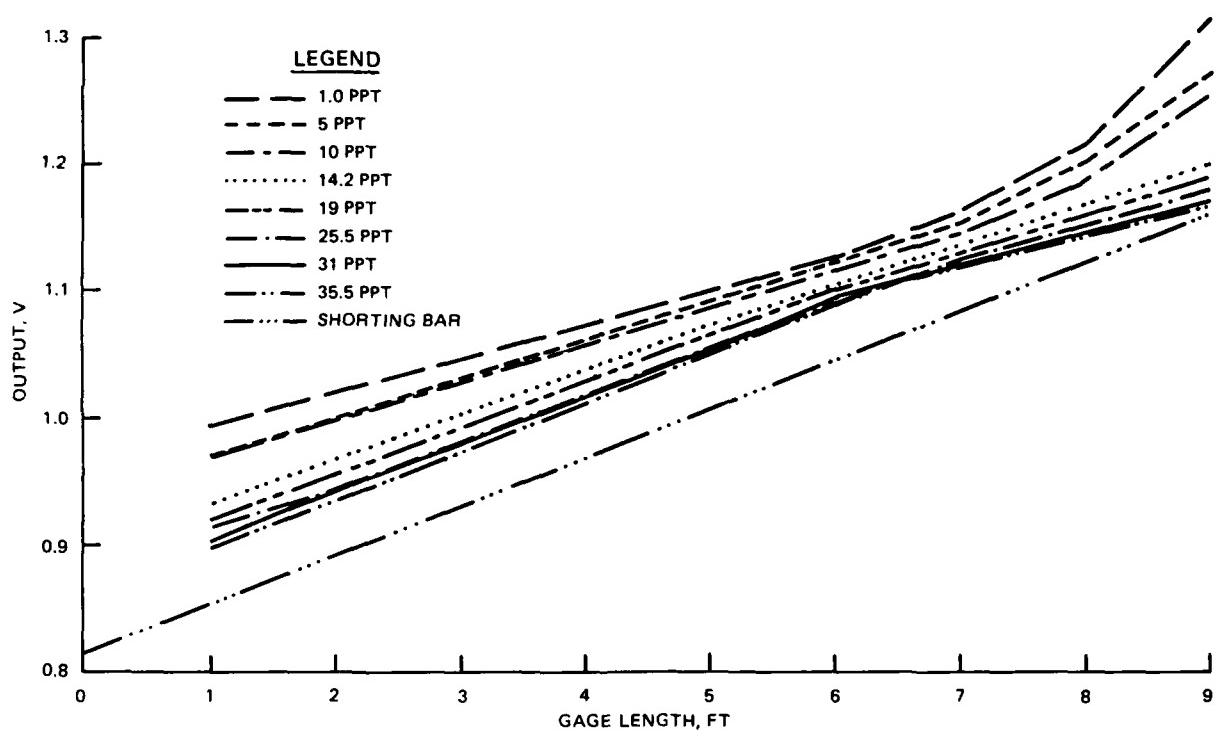


Figure 8. Variation in gage linearity as a function of salinity

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